generation volume. However, it should be understood that the methods disclosed herein can be applied to control deposition of essentially any plasma specie that has a differential mass distribution subject to thermophoresis effects, and that is capable of depositing as a protective layer on the substrate. Also, it should be understood that the plasma referenced herein can be generated through either inductive means, capacitive means, or a combination thereof. Additionally, the methods disclosed herein can be applied to plasma processing of essentially any type of substrate, including but not limited to semiconductor substrates, flat panel displays, solar panels, and the like.

[0058] While this invention has been described in terms of several embodiments, it will be appreciated that those skilled in the art upon reading the preceding specifications and studying the drawings will realize various alterations, additions, permutations and equivalents thereof. It is therefore intended that the present invention includes all such alterations, additions, permutations, and equivalents as fall within the true spirit and scope of the invention.

~~What is claimed is:~~

Claims:

1. A method for operating a plasma processing chamber, comprising:

obtaining a time-dependent substrate temperature to be applied during a plasma process, wherein the time-dependent substrate temperature at any given time is correlated to control of a sticking coefficient of a plasma constituent at the given time;

obtaining a time-dependent temperature differential between an upper plasma boundary and a substrate to be applied during the plasma process, wherein the substrate serves as a lower plasma boundary, and wherein the time-dependent temperature differential at any given time is correlated to control of a flux of the plasma constituent toward the substrate at the given time;

holding the substrate on a top surface of a substrate holder, wherein the substrate holder is disposed at a location below and spaced apart from an upper electrode assembly which defines the upper plasma boundary;

controlling a temperature of the substrate holder during the plasma process so as to control a temperature of the substrate in accordance with the obtained time-dependent substrate temperature; and

controlling a temperature of the upper electrode assembly during the plasma process so as to comply with the obtained time-dependent temperature differential between the upper plasma boundary and the substrate.

2. The method as recited in claim 1, further comprising:

measuring a temperature of the substrate holder during the plasma process;

generating a substrate holder temperature control feedback signal based on the measured temperature of the substrate holder; and

controlling the temperature of the substrate holder based on the substrate holder temperature control feedback signal to maintain the temperature of the substrate in accordance with the obtained time-dependent substrate temperature.

3. The method as recited in claim 2, wherein controlling the temperature of the substrate holder includes operating a heater within the substrate holder, a chiller within the substrate holder, or a combination thereof.

4. The method as recited in claim 2, further comprising:

measuring a temperature of the upper electrode assembly during the plasma process;

generating an upper electrode assembly temperature control feedback signal based on the measured temperature of the upper electrode assembly; and

controlling the temperature of the upper electrode assembly based on the upper electrode assembly temperature control feedback signal and the substrate holder temperature control feedback signal to maintain a temperature difference between the upper electrode assembly and the substrate holder in accordance with the obtained time-dependent temperature differential between the upper plasma boundary and the substrate.

5. The method as recited in claim 4, wherein controlling the temperature of the upper electrode assembly includes operating a heater within the upper electrode assembly, a chiller within the upper electrode assembly, or a combination thereof.

6. The method as recited in claim 4, further comprising:

measuring a temperature of peripheral components during the plasma process, wherein the peripheral components are located within the plasma processing chamber around a plasma generation volume;

generating a peripheral component temperature control feedback signal based on the measured temperature of the peripheral components; and

controlling the temperature of the peripheral components based on the peripheral component temperature control feedback signal to maintain a target temperature of the peripheral components during the plasma process.

7. The method as recited in claim 6, wherein controlling the temperature of the peripheral components includes operating a heater within the peripheral components, a chiller within the peripheral components, or a combination thereof.

8. The method as recited in claim 7, wherein the peripheral components include confinement rings, a peripheral shroud, or a combination thereof.

9. The method as recited in claim 6, wherein the target temperature of the peripheral components is specified as a function of time during the plasma process.

10. The method as recited in claim 1, wherein the plasma constituent is a polymer that is resistant to etching capabilities of the plasma process.

11. The method as recited in claim 1, wherein each of the substrate holder and the upper electrode assembly is defined to include multiple radially concentric temperature control zones, wherein the obtained time-dependent substrate temperature is provided for each of the multiple radially concentric temperature control zones of the substrate holder, and wherein the obtained time-dependent temperature differential between the upper plasma boundary and the substrate is provided for each of the multiple radially concentric temperature control zones of the upper electrode assembly.

Claims

1. A method for defining a plasma process to be performed on a substrate, comprising:

determining a time-dependent substrate temperature to be applied during the plasma process, wherein the time-dependent substrate temperature at any given time is determined based on control of a sticking coefficient of a plasma constituent at the given time;

determining a time-dependent temperature differential between an upper plasma boundary and a substrate to be applied during the plasma process, wherein the substrate serves as a lower plasma boundary, and wherein the time-dependent temperature differential at any given time is determined based on control of a flux of the plasma constituent directed toward the substrate at the given time; and

storing the determined time-dependent substrate temperature and time-dependent temperature differential in a digital format suitable for use by a temperature control device defined and connected to direct temperature control of the upper plasma boundary and the substrate during the plasma process.

2. The method as recited in claim 1, wherein the sticking coefficient is a temperature dependent parameter that represents an affinity of the plasma constituent to adhere to the substrate.

3. The method as recited in claim 1, wherein an increase in substrate temperature corresponds to a reduced sticking coefficient representing a lower affinity of the plasma constituent to adhere to the substrate, and

wherein a decrease in substrate temperature corresponds to an increased sticking coefficient representing a higher affinity of the plasma constituent to adhere to the substrate.

4. The method as recited in claim 1, wherein the time-dependent temperature differential is defined based on a thermophoresis effect on the plasma constituent, whereby higher mass portions of the plasma constituent move toward lower temperature regions, and whereby lower mass portions of the plasma constituent move toward higher temperature regions, and wherein the movement of the plasma constituent based on its mass and regional temperatures to which it is exposed controls the flux of the plasma constituent directed toward the substrate.

5. The method as recited in claim 1, wherein the plasma process includes a high aspect ratio feature etching process in which a number of high aspect ratio features are etched into one or more materials present on the substrate.

6. The method as recited in claim 5, wherein the time-dependent temperature differential between the upper plasma boundary and the substrate is set during the high aspect ratio feature etching process to ensure that the flux of the plasma constituent toward the substrate provides sufficient amounts of appropriate masses of the plasma constituent near the substrate and within the number of high aspect ratio features.

7. The method as recited in claim 6, wherein the time-dependent substrate temperature is set during the high aspect ratio feature etching process to ensure that a sufficient amount of the plasma constituent adheres to a mask on the substrate so as to preserve the mask through completion of the plasma process, and to ensure that a sufficient amount of the plasma constituent adheres to sidewalls of the number of high aspect ratio features to protect the sidewalls from being adversely undercut, and to ensure that the number of high aspect ratio features remain open through completion of the plasma process.

8. The method as recited in claim 1, wherein the plasma constituent is a polymer that is resistant to etching capabilities of the plasma process.

9. The method as recited in claim 1, further comprising:

determining a time-dependent substrate support temperature necessary to achieve the determined time-dependent substrate temperature, wherein the substrate is held in thermal contact with the substrate support during the plasma process; and

storing the determined time-dependent substrate support temperature in a digital format suitable for use by a temperature control device defined and connected to direct temperature control of the substrate support during the plasma process.

10. The method as recited in claim 1, wherein each of the time-dependent substrate temperature and the time-dependent temperature differential between the upper plasma

boundary and the substrate is defined as a function of radial position extending from a center of the substrate to a periphery of the substrate.

11. A method for operating a plasma processing chamber, comprising:

obtaining a time-dependent substrate temperature to be applied during a plasma process, wherein the time-dependent substrate temperature at any given time is correlated to control of a sticking coefficient of a plasma constituent at the given time;

obtaining a time-dependent temperature differential between an upper plasma boundary and a substrate to be applied during the plasma process, wherein the substrate serves as a lower plasma boundary, and wherein the time-dependent temperature differential at any given time is correlated to control of a flux of the plasma constituent toward the substrate at the given time;

holding the substrate on a top surface of a substrate holder, wherein the substrate holder is disposed at a location below and spaced apart from an upper electrode assembly which defines the upper plasma boundary;

controlling a temperature of the substrate holder during the plasma process so as to control a temperature of the substrate in accordance with the obtained time-dependent substrate temperature; and

controlling a temperature of the upper electrode assembly during the plasma process so as to comply with the obtained time-dependent temperature differential between the upper plasma boundary and the substrate.

12. The method as recited in claim 11, further comprising:

measuring a temperature of the substrate holder during the plasma process;

generating a substrate holder temperature control feedback signal based on the measured temperature of the substrate holder; and

controlling the temperature of the substrate holder based on the substrate holder temperature control feedback signal to maintain the temperature of the substrate in accordance with the obtained time-dependent substrate temperature.

13. The method as recited in claim 12, wherein controlling the temperature of the substrate holder includes operating a heater within the substrate holder, a chiller within the substrate holder, or a combination thereof.

14. The method as recited in claim 12, further comprising:

measuring a temperature of the upper electrode assembly during the plasma process;

generating an upper electrode assembly temperature control feedback signal based on the measured temperature of the upper electrode assembly; and

controlling the temperature of the upper electrode assembly based on the upper electrode assembly temperature control feedback signal and the substrate holder temperature control feedback signal to maintain a temperature difference between the upper electrode assembly and the substrate holder in accordance with the obtained time-dependent temperature differential between the upper plasma boundary and the substrate.

15. The method as recited in claim 14, wherein controlling the temperature of the upper electrode assembly includes operating a heater within the upper electrode assembly, a chiller within the upper electrode assembly, or a combination thereof.

16. The method as recited in claim 14, further comprising:

measuring a temperature of peripheral components during the plasma process, wherein the peripheral components are located within the plasma processing chamber around a plasma generation volume;

generating a peripheral component temperature control feedback signal based on the measured temperature of the peripheral components; and

controlling the temperature of the peripheral components based on the peripheral component temperature control feedback signal to maintain a target temperature of the peripheral components during the plasma process.

17. The method as recited in claim 16, wherein controlling the temperature of the peripheral components includes operating a heater within the peripheral components, a chiller within the peripheral components, or a combination thereof.

18. The method as recited in claim 17, wherein the peripheral components include confinement rings, a peripheral shroud, or a combination thereof.

19. The method as recited in claim 16, wherein the target temperature of the peripheral components is specified as a function of time during the plasma process.

20. The method as recited in claim 11, wherein the plasma constituent is a polymer that is resistant to etching capabilities of the plasma process.

21. The method as recited in claim 11, wherein each of the substrate holder and the upper electrode assembly is defined to include multiple radially concentric temperature control zones,

wherein the obtained time-dependent substrate temperature is provided for each of the multiple radially concentric temperature control zones of the substrate holder, and

wherein the obtained time-dependent temperature differential between the upper plasma boundary and the substrate is provided for each of the multiple radially concentric temperature control zones of the upper electrode assembly.

22. A system for plasma processing of a substrate, comprising:

a plasma processing chamber;

a substrate holder disposed within the plasma processing chamber and defined to hold a substrate, wherein the substrate holder includes one or more temperature control devices;

an upper electrode assembly disposed within the plasma processing chamber above and spaced apart from the substrate holder, wherein the upper electrode assembly includes one or more temperature control devices; and

a temperature control module defined to control the one or more temperature control devices of the substrate holder to maintain a target substrate temperature, the temperature control module further defined to control the one or more temperature control devices of the upper electrode assembly to maintain a target temperature differential between the substrate and the upper electrode assembly.

23. The system as recited in claim 22, wherein the target substrate temperature is a time-dependent substrate temperature to be applied during a plasma process.

24. The system as recited in claim 23, wherein the time-dependent substrate temperature at any given time is correlated to control of a sticking coefficient of a plasma constituent at the given time.

25. The system as recited in claim 22, wherein the target temperature differential between the substrate and the upper electrode assembly is a time-dependent temperature differential between the substrate and the upper electrode assembly to be applied during a plasma process.

26. The system as recited in claim 25, wherein the time-dependent temperature differential at any given time is correlated to control of a flux of a plasma constituent toward the substrate at the given time.

27. The system as recited in claim 22, further comprising:

a first temperature measurement device disposed to measure a temperature of the substrate holder, wherein the temperature of the substrate holder is correlated to the temperature of the substrate held thereon; and

a second temperature measurement device disposed to measure a temperature of the upper electrode assembly,

wherein each of the first and second temperature measurement devices is defined to convey respective temperature measurement signals to the temperature control module.

28. The system as recited in claim 22, wherein the one or more temperature control devices of the substrate holder includes a chiller and a heater embedded within the substrate holder.

29. The system as recited in claim 22, wherein the one or more temperature control devices of the upper electrode assembly includes a chiller and a heater embedded within the upper electrode assembly.

30. The system as recited in claim 22, wherein each of the substrate holder and the upper electrode assembly is defined to include multiple radially concentric temperature control zones with respective temperature control devices therein.